INNOVATIVE TECHNOLOGIES FOR VOLTAGE AND POWER FLOW CONTROL

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SUMMARY

Developments in semiconductors drive power electronic into transmission and distribution applications as solution of power flow control and voltage stability problems. Advances in power semiconductor technology and power electronic equipment have provided a means for fast and smooth control of three system parameters that have a direct impact on power flow: the bus voltage, the line impedance and the transmission angle [8]. This paper describes new means of power electronic concrete FACTS (Flexible Alternating Current Transmission Systems) devices. These devices can fulfil functions of reactive shunt compensation, series compensation, phase shifting, series voltage injection device and shunt current injection device or a combination of these. This article describes individual FACTS devices and their application for voltage and power flow control.

Installation of FACTS devices on key locations in a electric power network increases the network's controllability. By using these devices we can push transmission lines to their thermal limits [3]. This way we can update existing lines and delay construction of new lines. We also add flexibility which may be used to increase the efficiency of energy transfer and decrease the cost of generation. FACTS devices have been successfully applied in many countries. This paper describes in brief some examples of these applications.

This article also describes the Distributed Superconducting Magnetic Energy Storage System (D-SMES). Advantage of this system is the combination of superconducting and semiconductor technology.

Keywords: *FACTS devices, D-SMES, thyristor, voltage control, voltage stability, power flow control*

1. INDRODUCTION

New means of power electronic especially FACTS devices can provide us smooth control over the AC transmission systems. The latest produced FACTS devices are mainly basically semiconductors IGCT (Integrated Gate-Commutated Thyristor) and IGBT (Insulated Gate Bipolar Transistor).

Basic classification of FACTS devices [4]:

- SVC (Static VAR Compensator), can be given as:
  - STATCOM, SSC (Static Synchronous Compensator),
  - SSSC (Static Synchronous Series Compensator),
  - TCSC (Thyristor Controlled Series Capacitor),
- DVR (Dynamic Voltage Restorer),
- TCPAR (Thyristor Controlled Phase Angle Regulator),
- UPFC (Unified Power Flow Controller),
- UVC (Unified Voltage Controller),
- APF (Active Power Filter).

Between the latest FACTS devices is also included IPC (Interphase Power Controller).

Individual FACTS devices used for voltage control and power flow regulation are described in the following parts of this paper.

2. STATIC VAR COMPENSATOR

The SVC consists of a combination of fixed capacitors, thyristor-switched capacitors and thyristor-controlled reactors connected in parallel with the power system in most cases via a step-up transformer. The maximum SVC reactive currents are dependent on SVC terminal voltage. The reactive power produced or consumed by an SVC is generated or absorbed by passive reactive components. The controllable parameter in this equipment is the parallel capacitive or inductive susceptance. Within the SVC rating, its susceptance can be continuously controlled. When the SVC reaches its capacitive or inductive limit, it then acts as a parallel capacitor or reactor, respectively. [12]

SVC devices offer the following advantages [1]:

- very quick and infinitely variable reactive power conditioning,
- improvement of voltage stability in weak networks,
- increase of static and dynamic transmission stability and reduce of power fluctuations,
- enhancement of transmission capacity of lines,
- quick balancing of variable non-symmetrical loads,
- lower transmission losses,
- continuous regulation of power factor.

2.1 Components of compensator

Static VAR Compensator can be given in several types. The most of them have the following components [4]:

- TCR (Thyristor Controlled Reactor),
- TSC (Thyristor Switched Capacitor),
- TSR (Thyristor Switched Reactor),
- MSC (Mechanical Switched Capacitor).

- Thyristor Controlled Reactor

An inductance (reactor bank) is connected in series with thyristors. An inductance is controlled by them. The reactive power is continuously changed between zero and the maximum value by conduction angle control of the thyristors. In many cases, this configuration is operated together with TSC or MSC.

- Thyristor Switched Capacitor

Thyristor-switched capacitors (capacitor bank) are switched on or off, path by path. To avoid transients, the thyristors are fired when the thyristor voltage is zero. Applying reactors instead of capacitors, creates the TSR.

In the following figure are drawn some components mentioned above:

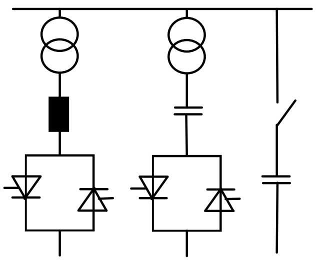

Fig. 1 Some types of SVC components

3. STATIC SYNCHRONOUS COMPENSATOR

A Static Synchronous Compensator consists of a voltage source converter (VSC), a coupling transformer and controls (Fig. 2). In Fig. 2, I_q is the converter output current and is perpendicular to the converter voltage V_i. The magnitude of the converter voltage and thus the reactive output of the converter (Q) is controllable. If $V_i > V_T$, the Statcom supplies reactive power to the AC system. If $V_i < V_T$, the Statcom absorbs reactive power.[5]

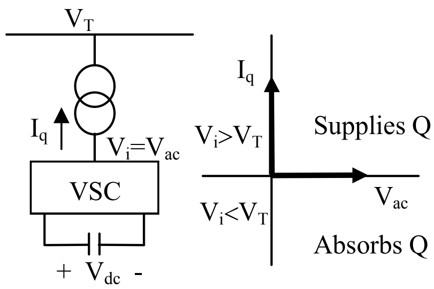

Fig. 2 Static Synchronous Compensator

4. STATIC SYNCHRONOUS SERIES COMPENSATOR

A Static Synchronous Series Compensator is a semiconductor voltage generator connected in series to the power system (Fig.3). It provides us exact two-direct power flow regulation in wider range than classical compensation components and it reduces of power fluctuations. [2]

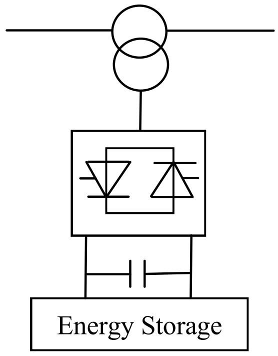

Fig. 3 Static Synchronous Series Compensator

5. THYRISTOR CONTROLLED SERIES CAPACITOR

We can control the series impedance of a transmission line by adding capacitors in series with the line. This allows us to reduce the total series impedance and lets us send additional power across the line. As shown in Fig. 4 the TCSC consists of thyristor controlled reactors (TCR) in parallel with capacitors. This configuration allows the fundamental frequency capacitive reactance to be smoothly controlled over a wide range and switched to a condition where bidirectional thyristor pairs conduct continuously and insert the reactance into the line.[3]

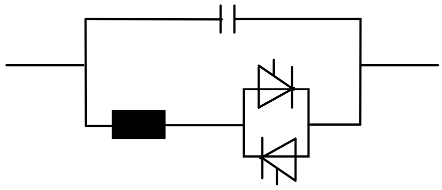

Fig. 4 A simple circuit model of the TCSC

6. DYNAMIC VOLTAGE RESTORER

The function of a Dynamic Voltage Restorer (DVR) is illustrated in Fig. 5. In the event of a voltage sag, the power electronic converter injects the appropriate voltage required into the supply bus to compensate for the sag. Rapid control cycles and millisecond switching speed of the converter enable accurate control of the voltage experienced by the load.

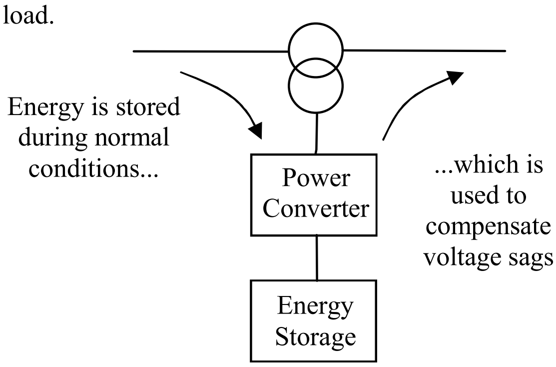

Fig. 5 Dynamic Voltage Restorer

Although a DVR may be rated to compensate up to a 90 per cent voltage sag, it does not support complete outages. Capacitors serve as energy storage device. A typical power range to be covered by DVR is from 3 MVA up to 50 MVA.[5]

7. THYRISTOR CONTROLLED PHASE ANGLE REGULATOR

Thyristor Controlled Phase Angle Regulator works in principle of longitudinal and shunt regulating transformer, but regulation is thyristor controlled. The TCPAR is controlled extremely quickly by a static thyristor based on-load tapchanger. The controllable parameter of the TCPAR is the voltage phase shift angle.

The active and reactive powers that are injected into the transmission line must be taken from the network by the shunt transformer and redirected to the boosting transformer (Fig. 6).

The thyristor-controlled phase angle regulator is one type of Phase-shifting transformers (PST) with equal input and output voltage magnitudes but with a phase shift between these voltages. [12]

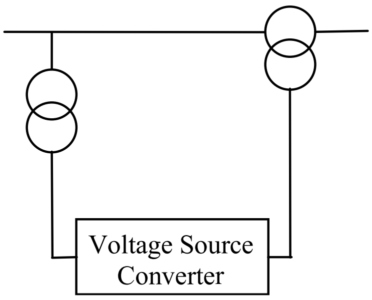

Fig. 6 Thyristor Controlled Phase Angle Regulator

8. UNIFIED POWER FLOW CONTROLLER

The Unified Power Flow Controller consists of shunt (exciting) and series (boosting) transformers. Both of these are connected by two IGCT converters and a DC circuit represented by the capacitor. In the figure 7, Converter 2 performs the main function of the UPFC by injecting an AC voltage with controllable magnitude and phase angle in series with the transmission line. The basic function of Converter 1 is to supply or absorb the active power demanded by Converter 2 at the common DC link [5].

One difference between the UPFC and a PST is that the UPFC reactive power injected into the line by the series branch does not need to be transmitted from the parallel branch. It is generated by the converter connected to the series branch. The active power injected into the system by the series branch must be taken from the system by the parallel branch and transmitted to the series branch over the DC circuit [12].

The UPFC in its general form can provide simultaneous, real-time control of all basic power system parameters (transmission voltage, impedance and phase angle) and dynamic compensation of AC system. Thereby, it can fulfil functions of reactive shunt compensation, series compensation and phase shifting.

A UPFC can regulate active and reactive power simultaneously. In principle, a UPFC can perform voltage support, power flow control and dynamic stability improvement in one and the same device.

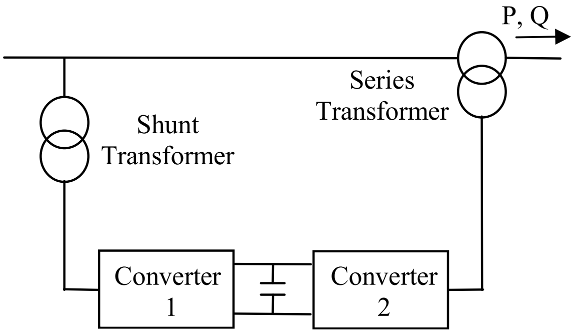

Fig. 7 Unified Power Flow Controller

9. UNIFIED VOLTAGE CONTROLLER

The Unified Voltage Controller injects voltage into the transmission line. It is used for network with big value of short circuit power, therefore it does not have to use means for accumulation of energy. At the terminals of a UVC is symmetrical three-phase system of voltages with equal voltage magnitudes. A UVC is also used for reactive power flow regulation and so it makes possible for change of power factor in the power system. [4]

In the following picture is drawn figure of a Unified Voltage Controller.

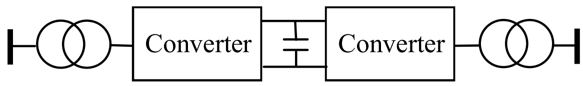

Fig. 8 Unified Voltage Controller

10. ACTIVE POWER FILTER

An Active Power Filter (APF) is a device that is connected in parallel to and cancels the reactive and harmonic currents from a group of nonlinear loads so that the resulting total current drawn from the AC main is sinusoidal.

The active power filters can be used in DC and AC electric circuits. According to system configuration it can be divided into series and parallel [4].

11. INTERPHASE POWER CONTROLLER

The Interphase Power Controller is a new technology developed by CITEQ (Canada) for the control of power flows within AC meshed networks. Although requiring not necessary the use of power electronics, it belongs to the FACTS devices family thanks to its characteristics.

The main purpose of this controller is to maintain a constant active power flow between two nodes of a network and to reverse the natural flow when necessary.

The IPC is a series-connected device where the essential components in each phase are conductor and a capacitor subjected to properly phase-shifted voltages.

The single-phase equivalent circuit of Figure 9 is the model used for power flow calculation. Whatever the method used for phase-shifting the internal voltages, the IPC always connects one phase of one side to two other phases on the other side; this is the origin of the name "Interphase" Power Controller.[11]

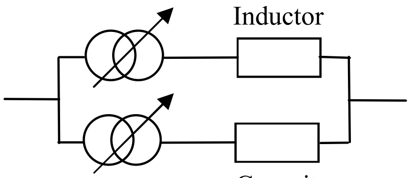

Fig. 9 Interphase Power Controller

12. APPLICATIONS OF FACTS IN ELECTRIC POWER NETWORKS

In generally before the FACTS application the following aspects are monitored [2]:

- system requirement and substantiality of technical solution
- capital costs and operational costs
- economic gains of implementation

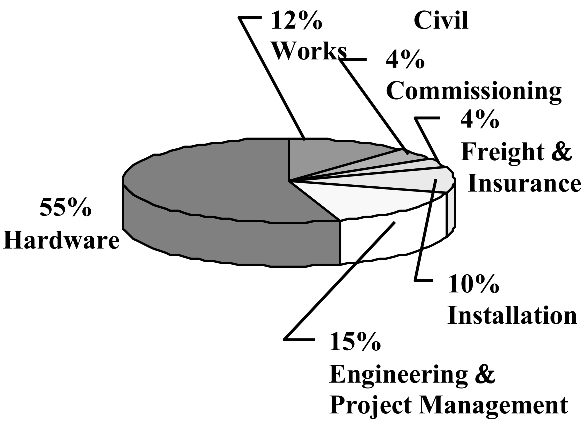

Fig. 10 Typical cost structure of FACTS installation

The cost of a FACTS installation depends on many factors, such as power rating, type of device, system voltage, system requirements, environmental conditions, regulatory requirements etc. Nevertheless, a typical cost structure for FACTS could be laid out as in Fig. 10. [5]

In Slovak Republic FACTS devices are not installed by reason of high costs. However in the foreseeable future we can expect changes by reason of electricity markets liberalisation.

For interconnections to serve their purpose, however, available transmission links must be powerful enough to safely transmit the amounts of power intended. If this is not the case, from a purely technical point of view it can always be remedied by building additional lines in parallel with the existing, or by uprating the existing system (s) to a higher voltage. This, however, is expensive, time-consuming, and calls for elaborate procedures for gaining the necessary permits. Also, in many cases, environmental considerations, popular opinion or other impediments will render the building of new lines as well as uprating to ultrahigh system voltages impossible in practice. This is where FACTS comes in. Examples of successful implementation of FACTS for power system interconnection can be found among others the Nordic Countries (Nordel), and between Canada and the United States. In such cases, FACTS helps to enable mutually beneficial trade of electric energy between the countries. Other regions in the world where FACTS is emerging as a means for AC bulk power interchange between regions can be found in South Asia as well as in Africa and Latin America [12]. Concrete examples of the STATCOM application are described for example in the article [9].

In the Europe are SVC devices installed in the following countries [6]:

- Norway: several SVC devices with maximal unit power up to 500 Mvar for 400 kV
- Sweden: several SVC devices with maximal unit power up to 400 Mvar for 400 kV
- Great Britain: several SVC devices with maximal unit power up to 450 Mvar for 400 kV
- Austria: 150 Mvar SVC unit for 400kV

13. SMES AND D-SMES TECHNOLOGIES

Between the latest technologies for improving power electric quality is classified Superconducting Magnetic Energy Storage System (SMES). This technology is based on the zero resistance property of superconducting wires for DC currents which can be sustained in substantially high magnetic fields. Coils made from these wires can generate fields, typically up to ten Tesla and the electromagnetic energy stored can be both extracted from the coil and injected into the coil very rapidly. At present energy storage coils for 1 MJ and above use liquid helium for cooling and the conductor is usually niobium-titanium.

In the last ten years small autonomous micro-SMES units have been developed for on-site power quality applications. The energy stored is about 1 MJ and it can be fed to a load at about 1 MW for up to about 1 second. This is ideal for correcting small momentary voltage fluctuations that can affect sensitive equipment or processes. After supplying its energy the coil is slowly recharged for a subsequent operation. [10]

The SMES technology can be used in combination with devices of power electronic. These devices, called D-SMES (Distributed Superconducting Magnetic Energy Storage System), have two main advantages. One is real energy storage through the use of superconductors and the other is instantaneous response through the use of power electronics. Superconductivity makes it possible, by eliminating resistive losses within the magnetic coil, to store and instantaneously discharge large quantities of power. The power electronics module, which consists of an IGBT-based voltage source inverter system, uses advanced power electronics to detect voltage sags ant to inject precise quantities of real and reactive power to boost voltage on the transmission system within a fraction of a cycle. D-SMES devices are most effective in addressing voltage stability problems. However, they can be used for other applications, such as flicker correction, capacitor bank switching, and other power quality solutions for both utility and industrial applications. Some of the benefits of using the D-SMES device are: faster voltage recovery when compared to other similar devices, distributed sources, low cost when compared to traditional solutions, quick and easy installation with short lead times, modular design to meet future load growth and portable in case it has to be moved to other locations. [7]

14. CONCLUSION

At the present time electricity industry is fast changing. It is related to restructuring and liberalisation of electricity market. This paper has described several devices which can help system operators run the transmission system more efficiently under the conditions of liberalised electricity market. Not many publications in Slovak or Czech Republic can be found on innovative means for AC transmission systems especially the FACTS devices. This paper offers integral view on these new technologies.

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BIOGRAPHY

Jozef Rusnák was born on 3.8.1977. In 2001 he graduated (MSc.) at the Department of Electric Power Engineering of the Faculty of Electrical Engineering and Informatics at Technical University in Košice. Now he is a internal post graduate (PhD.) student. Thesis title is "Operation Optimisation of Electric Power System Using an Artificial Intelligence Applications". His scientific research is focusing on Voltage Control Technologies, Optimal Power Flow Studies and using the Artificial Intelligence for Power System Control.